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High Sample Rate Sensor Imaging Technique

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14. ABSTRACT
This report summarizes the second-year efforts of Boston College personnel under AF contract F19628-03-C-0007. Efforts include the design and development of software for high sample rate sensors and activities to improve a suite of instruments to assist ground tests.

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1. INTRODUCTION

This report summarizes the second year efforts of Boston College personnel under AF contract F19628-03-C-0007. Our efforts include the design and development of software for high sample rate sensors, the activities to improve a suite of instruments to assist ground tests and the analysis of these measurements, the activities of our celestial team, and the activities of the targets/backgrounds working group.

2.0 High Sample Rate Sensor Imaging

One of our researchers continued to lead the design and implementation of a next-generation software suite to support this project. Our efforts for this effort will be divided into quarterly summaries.

2.1 First Quarter

We continued to implement the core data collection applications that will be used to collect data from one of several high sample rate sensors. Also we began to define the process for data analysis on this project, as components of this software suite will also be used to ingest, analyze and display experimental data.

Specifically, we achieved the following goals:

1) established data and file formats
2) brought on a new team member
3) began work on a user interface
4) refactored existing code to meet maintenance and performance needs
5) set up a private network for high sample rate sensor development, including source control and single sign-on features
6) refined the implementation of the data collection application.

2.1.1 Review: This project determined in late 3Q 2003 that there was a need for a new camera control and data-acquisition (CCDAS) application. This application has been the primary focus of our efforts at AFRL/VSBY.

The CCDAS application takes data from a sensor, does some minor pre-processing of the data and stores the data on disk. It has a graphical user interface which displays some of the data to the sensor operator who can then adjust the data collection settings or otherwise manipulate the system.

Originally targeted at a specific sensor, a goal of the CCDAS project is to make the software extensible to many different sensor types.

2.1.2 Accomplishments

2.1.2.1 Data and File Formats:

A side project to CCDAS is an effort to develop an analysis engine for the sensor data that can handle a data stream in near real-time. We collaborated with an AFRL/VSBY scientist on data formats and communications protocols for passing information between the applications. This effort is largely complete, and prototypes of both applications have been able to communicate properly.

2.1.2.2 User Interface:

The requirements for the Phase I delivery of CCDAS include a mechanism by which an operator can control the data collection process. Work has begun on delivering both a command-line and a graphical user interface to CCDAS, with an expected delivery date of 4Q 2004.

2.1.2.3 Code Refactor:

The requirements for the CCDAS project include some rather strict performance targets. Data are collected from the high sample rate sensor(s) at a rate that approaches the maximum data throughput of a high performance SCSI disk controller subsystem. In order to meet the data collection needs of the project, periodic design reviews and testing is required. A major goal of this quarter was to ensure the current CCDAS design could meet these needs; some code revision and re-design was required.

2.1.2.4 Software Development Infrastructure:

Due to the sensitive nature of the CCDAS project and to accommodate the growing number of contributors to the project, there was a need to establish a mechanism for source control, as well as a means for several developers to share limited computing resources. We implemented a private development network for software development. This network is isolated from the base LAN (in anticipation of project classification), and has resources for source control and the ability to use a single sign-on identity to authenticate to all resources.

2.1.2.5 Continued Progress on CCDAS Deliverables:

The major focus of our efforts was in the design and implementation of the CCDAS core software, i.e. the sensor interface and the data collection modules. Work on this continued as we work toward our Q4 delivery date. While much has been accomplished on this project, progress has been slowed by delays in acquiring the sensor models that the software is targeting. Notwithstanding this, a substantial body of code has been generated for all portions of the software that does not interface directly with the sensor. Despite these delays, we still feel a release date in Q4 2004 is achievable, barring additional delays in procurement.

2.1.3 Concluding Remarks:

The activities of 1Q 2004 have been to build out a robust software development infrastructure for this group, as well as create robust code for their data collection needs. It is our belief that the internal network and source control repositories will allow not only the software developers to keep versioned copies of their work, but that this will be extended to the data analysts as well. It is hoped that even presentations and papers will be kept in source control, allowing for easier collaboration, proofreading, and editing. The addition of a dedicated UI engineer and an early focus on developing the user interface application gives us the ability to ensure our Phase I deliverable is not only robust and powerful but also operator-friendly.

We entered into a sub-contract with the University of Louisville to provide sodium measurements needed for the program. The initial cost of this sub-contract is approximately $70,000. Additionally the University of Louisville was funded $100,000 to build two optical benches.

2.2 Second Quarter

2.2.1 Summary: One of our researchers continued to lead this program's next generation data acquisition software project toward a release date in mid Q3. This project encompasses applications to acquire, ingest and analyze data taken using high sample rate sensors. Specifically this software targets the next generation of high sample rate sensor, although it is designed to be extensible to any type of sensor that is of interest.

We accomplished the following during the second quarter:
1. defined the deployment runtime environment for the sensor platform
2. prepared third party vendor code so that it could be integrated into the project
3. created Unix system infrastructure software components
4. coordinated the integration of user interface and real time data analysis into the application
5. identified software tools for debugging and testing the application

2.2.2 Discussion:

We have been responsible for the design and production of a next-generation data acquisition system. The second quarter of 2004 saw much activity on this task as we come closer to a release date of late Q3 for this software. Most of our accomplishments this quarter are tightly coupled to the composition of this software package.

2.2.2.1 Deployment Runtime Environment:
Due to the stringent runtime performance requirements of the sensor software and the need to be able to replicate this environment in a rigorous way, one of our researchers spent time codifying the build process for a high sample rate instrument computer. As we get closer to the field deployment date, it will be important not only to document the

build process but also to automate and script as much as possible. The goal for this effort is to make it simple to recreate or duplicate a host computer for the sensor software.

2.2.2.2 Vendor Code Integration

Data collection requires data inputs not only from the sensor via a frame-grabber card, but also GPS measurements taken simultaneously. The hardware purchased for the project had vendor provided software to demonstrate its functions, but this code needed to be neatly integrated and added to our application in a shared library format. This was accomplished; the sensor application build process is actually able to detect the presence of the hardware and build/link which libraries are needed without any input on the part of the builder.

2.2.2.3 Unix System Infrastructure

One of our researchers created software components to abstract low level Unix network and signal handling into a more developer friendly objects. As the code makes heavy use of both Unix signals and network infrastructure, this was a necessary accomplishment. These components will be able to be used easily in other software for this project.

2.2.2.4 UI and Analysis Integration

Both a graphical user interface and a real-time data analysis engine are incorporated into the sensor software and utilize common infrastructure. As both of these sub-projects reach maturity the need to be smoothly integrated into the existing code base and tested as part of the entire application, not just as stand-alone units. Q2 saw the beginning of this effort, where the sensor software suite becomes a complete application instead of a collection of discrete units.

2.2.2.5 Debugging and Testing Tools

The sensor software is a complex multi-threaded application, and as such it is difficult and time-intensive to debug. One of the accomplishments of this quarter was to examine potential tools that we can use to ease this process. Several tools were explored, with a short list of potential candidates generated.

2.3 Third Quarter

2.3.1 Summary: One of our researchers was responsible for continued progress in support of this program's sensor project. His chief accomplishment during this period was to finish work on all required features of the sensor software. A prototype of this software successfully acquired data and displayed analyzed data in real time during an experiment using model rocketry engines. I anticipate a delivery date in Q4 for Version 1.0 of this package.

We accomplished the following during this quarter:

1. Demonstrated sensor software
2. Surveyed image stabilization techniques for inclusion in the software
3. Finalized sensor delivery schedule and feature list

2.3.2 Discussion:

2.3.2.1 Demonstration of Sensor Software

The sensor project has a target sensor. However, delivery of these instruments was delayed until very late in Q3, so there was a desire to see the software in operation with another camera. During Q3 I modified the software to be able to easily change cameras, and so it is now able to use almost any sensor that is supported by the EDT frame grabber hardware we specified. We successfully used the camera system to take data during a joint experiment with SNHI, demonstrating that the software works as designed, even with a different sensor.

2.3.2.2 Survey of Image Stabilization Techniques

One of the issues confronting the image stabilization is the problem of pointing jitter in the sensor. An unstable sensor contributes the content to image from this jitter, so it is important to explore techniques of minimizing the effects of sensor motion on high sample rate measurements. During Q3 we explored the problem and examined methods that others have used to reduce or eliminate pointing jitter in the sensor, based on both software (using image registration and compositing) and hardware (using an adaptive feedback mechanism to mechanically stabilize the sensor). The results of this survey were provided to the Contract Monitor

2.3.2.3 Finalized Sensor Delivery Schedule and Feature List

Upon delivery of the actual instruments, the schedule for delivery of the software and the feature list that Version 1.0 of the software will support was finalized. We will deliver Version 1.0 in Q4 of 2004, and at time we will present a clear roadmap of feature enhancements and extensions for future work.

2.4 Fourth Quarter

2.4.1 Summary: One of our researchers oversaw the delivery of version 1.0 of the high sample software. This product meets all of the documented requirements. The software was used as a demonstration at the MDA TER meeting in December 2004, where it surpassed expectations for reliability and robustness.

2.4.2 Accomplishment:

1. Delivered sensor software, including user interface, camera control daemon and preliminary real-time analysis application.

2.4.3 Discussion:

Despite delays in equipment arrival and late changes to requirements, we delivered the first version of sensor software to this team in Q4. This software is a full replacement for the previous programs used to take data from high sample rate instruments. Key requirements for software included:

- Reliability and stability
- Single point of control

- Able to support multiple instruments
- Easily extensible for future instruments
- Able to be integrated with real-time analysis software

These requirements were met in the delivered product. At the TER meeting, the software ran for 12 hours at a time, and was able to smoothly handle detection and discrimination of a target in a cluttered scene, using only a single laptop computer for camera control, user-interface and real-time analysis.

Additional efforts were spent in the final adjustment and programming of the sensor instrument. This instrument is the best supported of all potential instruments. However, other cameras currently work with the software. Bringing these other instruments to the same level of support is a focus for further work, but should be a modest amount of effort.

3.0 Instrument Measurement Suite

The Multiple Wavelength Lidar Trailer (MWLT) was deployed to the Energetic Materials Research and Testing Center (EMRTC) to support the Bulk Chemical Experiment, sponsored by the Missile Defense Agency's (MDA) Corporate Lethality Program. The trailer was packed at Hanscom AFB and set back up in the field in time for the experiment. The field campaign lasted approximately two weeks, during which lidar data was successfully collected for a total of four shots.

Upon return of the system to Hanscom AFB after supporting the Bulk Chemical Experiment, sponsored by the Missile Defense Agency's (MDA) Corporate Lethality Program., various improvements were effected to better prepare for future deployments. Structural work was done on the trailer as well as the optical table, cabinets and racks within to allow for safer transport of the system. RF interference of the data acquisition system from the motors that control the pointing of the hemispherical scanner was also addressed, and the problem has been greatly minimized. Extensive testing of the data acquisition system followed these improvements. In order to prepare the system for the PAC-3, various improvements and modifications were made to achieve the inter-sensor communication and high accuracy in pointing necessary. New cameras and lenses were researched and ordered. The scanner camera mount was redesigned to accommodate a second camera. In addition, the existing and new camera mounts were redesigned to provide a more stable platform for viewing. The beam expander for the 1064 nm channel needed to be redesigned and re-built in order to provide more latitude in pointing.

A new beam alignment procedure was used for MWLT while it was at Hanscom. The procedure was designed to maintain accurate pointing of the beam as it is scanned through azimuth and elevation. In addition, the procedure was designed to be quickly reproducible after being disassembled and then re-assembled in the field.

Communications in previous missions were found to be unacceptable, leading to problems at critical moments. An intercom system capable of uniting MWLT, MAPM, AFCPR Radar and W-Band Radar systems with Mission Control was researched, ordered and implemented.

At the end of April, one of our researchers visited White Sands Missile Range (WSMR) to perform a site survey for the upcoming PAC-3 DT-12a experiment. In addition to interfacing with the various personnel who will be assisting us in this project, he visited several possible sites at WSMR that were being considered for our set-up of the AFRL sensors Suite. The Tula-G site has been chosen for this experiment.

In June, MWLT, along with the Mobile Atmospheric Pollutant Mapper (MAPM), the Air Force Cloud Profiling Radar (AFCPR) and the ProSensing/UMass W-Band Radar, was deployment to the 3K North site at EMRTC to participate in the next phase of testing. This project lasted three weeks in which data was obtained for STTR Task 5, sponsored by BAE Systems. Before the actual deployment to the site, one of our researchers performed a study to determine possible topographical interference to the performance of MAPM in acquiring wind profiles to be used to further support the tests.

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3.1 Intercept Debris Measurement Program (IDMP)

MDA's IDMP program is founded on the Hanscom AFB AFRL multiple wavelength sensor suite and its ability to make range-resolved co-pointing calibrated backscatter measurements of the post intercept debris cloud of target missiles or their warheads. These measurements are desperately needed to quantify the intercept's lethality and help validate intercept lethality models. Analysis of these measurements provides estimates of the droplet size distribution of the cloud and its evolution as well as determination of the initial intercept cloud expansion rate. Based on comparison of multiple wavelength backscatter measurements of the same measured cloud volume, reliable estimates can be made of the modal or median droplet size, and assuming a physically-based droplet size distribution, estimates of number density, cloud volume, and cloud mass. DOD studies have shown that droplet size distribution is the single most important factor in determining bulk chemical agent ground lethality.

The AFRL IDMP sensor suite for this test included the six wavelength configuration consisting of the Multi-Wavelength Lidar Trailer (Nd:YAG lidar using wavelengths of 355 nm, 532 nm, and 1064nm), MAPM CO_2 heterodyne Doppler lidar (10.6 μm), Air Force Cloud Profiling Radar (Ka-band 8.57 mm), and the U. Mass. W-band radar (3.16 mm). This instrument suite was deployed White Sands Missile Range (WSMR), Dust Site to support the SMDC Intercept Debris Measurement Program (IDMP). These wavelengths span the optical and mm-wave atmospheric windows. A fundamental capability of the multiple wavelength sensor suite is its ability to perform very accurate co-pointing (within 0.3° angular resolution) over a wide range of azimuth and elevation angles. This uses a LAN-based system with sophisticated network server software driving the mirror or antenna mounts. This accurate co-pointing allows for range-resolved backscatter measurements of the same cloud volume at slant ranges exceeding 50 km for all six IDMP wavelengths. Careful star and camera bore sight alignments by each of the sensors are necessary to achieve the co-pointing accuracy.

For this particular test, a Storm target missile, built around a Pershing II Reentry Vehicle, was intercepted by a Patriot Advanced Capabilities 3 (PAC-3) missile interceptor. The target vehicle carried a simulated bulk chemical warhead containing 150 kg of thickened Tributyl phosphate (TTBP). AFRL sensors tracked in network co-pointing mode the missile target from shortly after launch until intercept using an external tracking data feed from White Sands Missile Range Mission Control. The Storm target vehicle, launched from Ft. Wingate, Arizona, was intercepted during the test in the lower stratosphere over White Sands on 18 November at 1433 GMT. AFRL sensors successfully tracked the post-intercept cloud for up to 45 minutes after intercept with at least 12 minutes of co-pointing multiple wavelength backscatter measurements obtained immediately following the intercept. All calibrated backscatter data taken following intercept were classified by the test directors and mailed later to Hanscom AFB. The classified backscatter data will be analyzed during the next two months with a final report prepared and delivered to MDA in early 2005.

One particular challenge one of our senior scientists was involved with during the test was planning the post-intercept cloud tracking strategy. Due to drop size dispersion associated with the size-dependent terminal velocity and vertical wind shear, it became necessary to provide time dependent information on sensor pointing angles, including elevation angle and azimuth angle. In addition, two scenarios involving a high altitude and low altitude intercept had to be planned for where the intercept cloud evolution and droplet dispersion would be markedly different in each scenario. Droplet trajectory predictions for a range of droplet sizes were provided toward this goal. These were to be especially helpful when, after several minutes, the cloud became invisible and significant angular or spatial dispersion of particle sizes occurred. In this case, the lidars could "break lock" and track smaller particles while the radars would track the larger particles. In addition, cirrus or other thin cloud would likely be present which requires an ability to discriminate between the anticipated location of the debris cloud droplets and other cloud particles. Finally, the target track data feed up to intercept from WSMR Mission Control was not considered reliable and it was imperative to have in advance a nominal "go-to" point and subsequent tracking strategy in event of the target track loss.

The mission was successfully completed, and MWLT arrived at Hanscom in early December. Several necessary changes in the system became obvious during the three-week campaign. Work has been started on re-designing the 1064 nm beam expander, stabilizing the scanner mirrors and improving the video feed from the cameras.